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Evaluation of the operation efficiency on low-carbon urbanization in world natural and cultural heritage area: a case study of Leshan city

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Abstract. In this paper, taking Leshan center municipal district (LSD) for instance, where one of the world natural and cultural heritages — the Leshan Giant Buddha locates, we make the efficiency evaluation of the urbanization level with rough set theory and improved DEA model, and give some advice according to the results in WNCH area. Firstly, we collect a lot of relative indexes, and select the most effective ones of them as evaluation basis by rough set, and then use improved DEA method to evaluate the efficiency level of low carbon urbanization. In this paper, we combine the idea of low carbon into urbanization, a new concept, to analyze on how to balance urbanization and the conservation of world natural and cultural heritages.

Keywords: world natural and cultural heritage, low carbon, urbanization, rough set, improved DEA

1 Introduction

The conception of the "World Heritage" was first proposed by UNESCO (United Nations Educational, Scientific and Cultural Organization) in the Convention Concerning the Protection of World Cultural and Natural Heritage (1972). There is a great significance in the conservation of common cultural and natural heritage of human beings[1]. While the world natural and cultural heritages (WNCH) are the great wealth we human beings inherits, but how to conserve them and preserve them, that is a question. With the development of economy globalization and modernization, the process of urbanization[2] accelerates, our human activities have caused serious impact on the natural and cultural environment we live, making the world natural and cultural heritages (WNCH) been abandoned or damaged greatly[3]. Therefore, we use the idea of low carbon to compromise with the urbanization development, that is low carbon[4] urbanization, which constructs low carbon city with low energy consumption, low emissions, high efficiency and output as features. So there are far more factors need to be concerned when analyzing it.

The ideal state of low carbon rural-urban integration emphasizes on the following that, the requisites of production flow among different industries fluently and orderly; narrow the gap between them in terms of society about the benefit allocation between; integrate the provincialism modern city civilization to make the all-round development of both society; combine production and living activities with the ecosystem and in turn, to make the whole system more sharing, more sustainable and joint-developed. So there are far more factors need to be concerned when analyzing the level of urbanization.

There are some difficulties in quantizing the development of low carbon urbanization, but we can evaluate the efficiency of it. We will have our our methods to analyze it. Considering the complexity and omnibearing of world natural and cultural heritage (WNCH) areas and low carbon urbanization itself, this paper here is to apply the rough set and data envelopment analysis (DEA) model into the efficiency research, taking Leshan center municipal district for instance, to estimate it with classified multiple inputs and outputs and make an

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objective appraisal, at last, give some advice on how to develop low carbon urbanization mode in WNCH areas and the world.

2 Modelling

It is our bounden responsibility to make an efficient assessment of low carbon urbanization and to do the job well by scientific methods. Firstly, we select the relative evaluation indexes, and establish the evaluation model of rough set theory and improved DEA to appraise low carbon urbanization. And the steps are as follows.

2.1 Index selection

This report, referring to the national definitions and requirements of low carbon and urbanization and our own understanding of it, with the local conditions of world natural and cultural heritage (WNCH) areas combined, we establish the evaluation system of low carbon urbanization in WNCH areas, following principles of evaluation of science, operability, completeness, dynamics, systematicness. Therefore, the efficiency of low carbon urbanization in WNCH areas needs to be evaluated from several aspects as follows: economic development[5, 6], social development[7], environmental factor[8–10]. And we list Tab. 1 according to the index system established as follows.

Firstly, the economic development. Usually, people are more likely to use population development to measure the level of urbanization, moreover, to use the division of urban population by total population, which can be a little incomplete or imperfect. However, as for the low carbon urbanization, there are much need to explain. We select the following indicators to reflect it: the ratio of agricultural social labor, a relative ratio of labor force attending collective economy organizations; GDP per capita, reflecting the level of economy or development stage of a region directly; the average per capita income in rural area, which can be calculated with dividing the net income by total population; the proportion of primary industry in GDP, indicating the growth of economy; the share of first industrial in all employees, reflecting rural urbanization and agricultural modernization; ratio of output value of third industry to second industry, indicating the change of industrial structure; contribution rate of gross asset, reflecting the profitability of all the assets and the embodiment of the level of business performance and management; average labor productivity of all employees, the consumption and output of living labor from the perspective of labor; the share of R&D funds in GDP , reflecting the development level of high-tech industries and the the use of high technology to upgrade traditional industries; ratio of net income per capita in urban area to rural area, the gap between urban and rural income levels.

Secondly, the social development. In fact, the social service refers more than we could imagine like education, science, medical and health service, employment, market supervision and so on, all of which has promote the economy development more effective, steady and harmonious. Here, we list the following several indexes to describe: ratio of urban population, an usual way to measure the level of urbanization for its simple calculation; the Engel's coefficient, referring to the proportion of residents' food expenses of the living expenses; ratio of urban Engel's coefficient to rural Engel's coefficient, the changes of consumption structure; education funds per capita and expenses of public health per capita, both indicating the public welfare and social security; number of patents and technological achievements, indicating the ability of independent innovation in a certain extent; growth rate of the second industrial employees, reflecting the employment situation that industry contributed to absorb labor force; urban registered unemployment rate, reflects the relative utilization of urban human resources and the overall operating conditions; the share of college degree or above in total population, the quality of workers; ratio of urban per capita net income to rural per capita net income, the gap between urban and rural income levels.

Thirdly, environmental factor. Often, there are some environmental factors that are influenced by the process of urbanization[11]. The indicators reflecting the degree of low-carbon urbanization in resources and the environment include: disposal and use rate of industrial solid waste; discharge rate of industrial waste water; urban water consumption rate, which is the division of non-agricultural population of urban water consumption and the total non-agricultural of urban area; the green area per capita and urban green coverage rate, which reflect government efforts on public environmental service; growth rate of environmental investment; the electricity consumption per 10 thousand output and comprehensive energy consumption of 10 thousand GDP, that the urbanization focus on resource conservation and efforts to reduce resource consumption.

Table 1. Index system of urbanization

Subsystem layer	Indicator name	Symbol	Unit
Economic development	Ratio of agricultural social labor	x_1	%
	GDP per capita	x_2	10^4 Yuan
	Average income per capita in rural area	x_3	Yuan/person
	Proportion of primary industry	x_4	%
	The share of primary industry in all employees	x_5	%
	Ratio of output value of third industry to secondary industry	x_6	%
	Contribution rate of gross asset	x_7	%
	Average labor productivity of all employees	x_8	%
	The share of R&D funds in GDP	x_9	%
	Ratio of net income per capita in urban area to rural area	x_{10}	%
Social development	Ratio of urban population	x_{11}	%
	The Engel's coefficient	x_{12}	%
	Ratio of urban Engel coefficient to rural Engel's coefficient	x_{13}	%
	Education funds per capita	x_{14}	Yuan/person
	Expenses of public health per capita	x_{15}	Yuan/person
	Number of patents and technological achievements	x_{16}	No dimension
	Growth rate of industrial employees	x_{17}	%
	Urban registered unemployment rate	x_{18}	%
	The share of college degree or above in total population	x_{19}	%
Environment factor	Urban water consumption rate	x_{20}	%
	The green area per capita	x_{21}	m^2
	Urban green coverage rate	x_{22}	%
	Electricity consumption of 10 thousand GDP	x_{23}	kwh
	Comprehensive energy consumption of 10 thousand GDP	x_{24}	$10^{-3}TCE$
	Disposal and use rate of industrial solid waste	x_{25}	%
	Discharge rate of industrial waste water	x_{26}	%
	Growth rate of environmental investment	x_{27}	%

2.2 Evaluation system

The indexes system we established has redundant problem and there are closely correlation between some indicators, so we use rough set knowledge reduction method to remove redundant indexes in the Tab. 1. Rough sets theory (RST) is a machine-learning method, which is introduced by Pawlak[12, 13] in the early 1980s, has proved to be a powerful tool for uncertainty and has been applied to find description of sets of objects in terms of attribute values, check dependencies (full or partial) between attributes, reduce attributes, analyze the significance of attributes, and generating decision rules. It can simplify the indicators in the premise of retaining key information and obtain the minimum expression of the knowledge.

2.2.1 Rough set theory

In the Rough sets theory, information systems are used to represent knowledge. The notion of an information system presented here is described in Pawlak and Hampton[14–17]. By an information system we understand the 2-tuple $S = (U, R)$, where U is a nonempty, finite set of objects, called the universe, R is a nonempty finite set of attributes, let $r \in R$ is a property of U, $[x]_r$ are the equivalence classes on the properties of the elements of U, and $x \in U$.

Let $P \subseteq R$, $P \neq \emptyset$, $P = \{r_{i1}, \cdots, r_{ik}\}$, the intersection of all equivalence relations of P is $\bigcap P = \bigcap_{j=1}^{k} r_{ij}$, then $\bigcap P$ is an equivalence relation, noted $IND(P)$, the intersection is not clear.

$Q \subseteq R$ is independent and $IND(Q) = IND(P)$, then Q is the reduction of P. All the properties of P which can not be omitted is the core of P, that $core(P)$.

By using RST, we obtain a new index, and that just be the inputs indicators in DEA model. We evaluate n years' operational efficiency of low-carbon urbanization in a region, so we assume n DMUs that one year is a decision making unit, and each year has m inputs and s outputs.

2.2.2 Dea model

We will improve the DEA model to evaluate the efficiency of low carbon urbanization. Data envelopment analysis (DEA) was first introduced by [18], which gives us an objective way that has already removed subjective factors. Suppose there are n DMUs to be evaluated against m inputs and s outputs. And the relationships between inputs and outputs are as follows Tab. 2:

Table 2. the relationship between inputs and outputs

	Index	Weight	Department					
			1	2	$\cdots$	j	$\cdots$	n
Inputs	1	v_1	x_{11}	x_{12}	$\cdots$	x_{1j}	$\cdots$	x_{1n}
	2	v_2	x_{21}	x_{22}	$\cdots$	x_{2j}	$\cdots$	x_{2n}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	m	v_m	x_{m1}	x_{m2}	$\cdots$	x_{mj}	$\cdots$	x_{mn}
Outputs	1	u_1	y_{11}	y_{12}	$\cdots$	y_{1j}	$\cdots$	y_{1n}
	2	u_1	y_{11}	y_{12}	$\cdots$	y_{1j}	$\cdots$	y_{1n}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	p	u_p	y_{p1}	y_{p2}	$\cdots$	y_{pj}	$\cdots$	y_{pn}

Technical efficiency is basically a measure by which the DMUs are evaluated for their performance relative to other DMUs in a sample, which is also called global efficiency[19]. The model can be developed by the following four parts.

1. Decision variables. The weight value matrix of the inputs and outputs are as follows:

$$\begin{aligned} &\text{Weight value matrix of } U\ I\text{:} \quad V = (v_1, v_2, \cdots, v_m). \\ &\text{Weight value matrix of } UO\text{:} \quad U = (u_1, u_2, \cdots, u_s). \end{aligned} \tag{1}$$

2. Objective function. According to the classical benefit and cost theory, the efficiency index of $j - aDMU_j$ is

$$E_{jj} = U^T UO_j / V^T UI_j = \sum_{k=1}^{s} u_k UO_{kj} / \sum_{i=1}^{m} v_i UI_{ij}, j = 1, 2, \cdots, n,$$

therefore the objective function is Eq. (2):

$$\max \quad \sum_{k=1}^{s} u_k UO_{kj} / \sum_{i=1}^{m} v_i UI_{ij}. \tag{2}$$

3. Constraints. Firstly, we assume $\Theta = \sum_{k=1}^{s} u_k UO_{kj} / \sum_{i=1}^{m} v_i UI_{ij} \leq 1$, that Θ is efficiency value, followed $0 \leq \Theta \leq 1$. Then the objective function must follow Eq. (3) :

$$\sum_{k=1}^{s} u_k UO_{kj} / \sum_{i=1}^{m} v_i UI_{ij} \leq 1. \tag{3}$$

in general, the bigger the Θ, DMU_j can deserves a larger output by a smaller investment. Secondly,the weight value matrix of the inputs and outputs should follow Eq. (4) :

$$u_k \geq 0, k = 1, \cdots, s, v_i \ \geq 0, i = 1, \cdots, m \tag{4}$$

4. Other parameters. Inputs matrix $UI = (ui_1, ui_2, \cdots, ui_m)^T$ and outputs matrix $UO = (uo_1, uo_2, \cdots, uo_s)^T$, thus (UI_j, UO_j) corresponding to the input and output of $j - a \ DMU_j$, that is $UI_k = (ui_{1k}, ui_{2k}, \cdots, ui_{mk}), UO_k = (uo_{1k}, uo_{2k}, \cdots, uo_{sk})$.

Above all, we conclude the following Eq. (5) , the relative efficiency optimization evaluation model of $j_{j0}th$.

$$\max \ h_{j0} = \frac{\sum\limits_{r=1}^{p} u_r UO_{rj0}}{\sum\limits_{i=1}^{m} v_i UO_{ij0}}$$
$$\text{s.t.} \begin{cases} \frac{\sum\limits_{r=1}^{p} u_r UO_{rj}}{\sum\limits_{i=1}^{m} v_i UI_{ij}} \leq 1, & j = 1, 2, \cdots, n \\ v_i, u_r \geq 0, & i = 1, 2, \cdots, m; \ r = 1, 2, \cdots, p \end{cases} \tag{5}$$

The CCR model comprehends both technical and scale efficiencies. Therefore, Banker et al.[20] developed a model in DEA, which was called BCC model to calculate the technical efficiency of DMUs, as well, called pure technical efficiency or local efficiency. And it assumes variable returns to scale (VRS).

Our aim is to calculate the Θ to check if it has reached to 1 or not. To calculate the efficiency, such as Suji, in principle, we should adopt the formula above, with the outputs and inputs data as variables, and divide them. However, to make the calculation process simpler and more convenient, we make some transformation, in guidance of mathematics, through dual transformation with slack variable concerned to get a linear programming[21]. Just as what they said, when a DMU has optimal solution $\Theta = 1$, that is effective; when $\Theta < 1$, that is ineffective, $1 - \Theta$ is the largest proportion of diminish investment, so if Θ is closer to 1, that the efficiency of the DMU is more effective. Efficiency value of effective unit is defined as 1, that $\Theta = 1$.

In order to explain the models further, now we suppose there are four DMUs named A, B, C, D, and each of them has d inputs UI_i and one output UO_i. Among them, A, B, C are effective that they form a production frontier ABC together, which we named y^0, while D is ineffective and enveloped by the production frontier, then all the units can only operate themselves on the frontier or at the lower left of it. Fig. 1 illustrates the relevant ideas of the efficiency evaluation. Suppose D' is the projection of D on the production frontier, and $y_{D'}$, y_D are the projection of D' and D respectively, thereby, $y_{D'} = 1$ while $y_D < 1$ and the efficiency of D is $y_D / y_{D'} < 1$. Thus it can be seen that, the efficiency value of effective unit is 1, while the efficiency value of ineffective unit is less than 1.

2.2.3 Super efficiency model

After we make sense of the basic knowledge of DEA, including the concepts, aims, principles and methods. And then, we give some more further explanations. Traditional DEA models do not allow for ranking DMUs, specifically the efficient ones. Since this model may derive multiple effective DMUs, that is there are not only one efficiency value equals to 1, which would make it difficult to evaluate them effectively. Meanwhile, in DEA, because of the unrestricted weight flexibility problem, it is possible that some of the efficient units are better overall performers than the other efficient ones[22]. In order to overcome this problem, a well known method named super efficiency model initially developed by Peterson[23, 24]. The super-efficiency DEA eliminates the upper bound on the technical efficiency score and provides additional information regarding the relative performance of the efficient unit. In the process of evaluation a DMU, we use the inputs and outputs linear combination of other DMUs, excluding the objective unit, so that to compare the effective DMUs. Therefore, we establish constraints as Eq. (6) .

$$
\min \quad \Theta
$$
$$
s.t \begin{cases} \sum\limits_{j=1, j\neq k}^{n} \lambda_j UI_j \leq \Theta UI_k \\ \sum\limits_{j=1, j\neq k}^{n} \lambda_j UO_j \leq UO_k \\ \lambda_j \geq 0, \quad j = 1, 2, \cdots, n \end{cases} \tag{6}
$$

In Eq. (6), λ_j is a re-constructed combined ratio of $j-a$ DMU of an effective DMU combination. When evaluating the efficiency of $k-a$ decision making units, let the input and output of $k-a$ DMU be substituted by the linear combination of inputs and outputs of all the other DMU, while exclude the $k-a$ DMU; For an effective DMU, its inputs can be increased in proportion but the efficiency value unchanged, and the increased proportion is the super efficiency evaluation value, so the larger the efficiency value of effective DMU and Θ, the effective DMU is more effective[25].

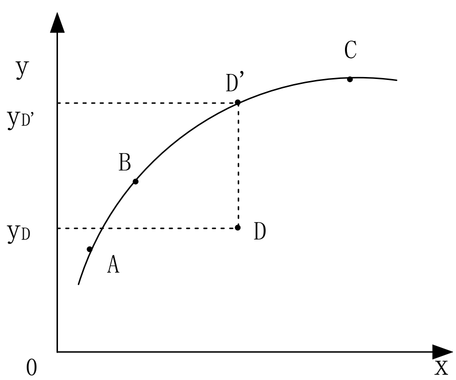

Fig. 1. Evaluation model of DEA

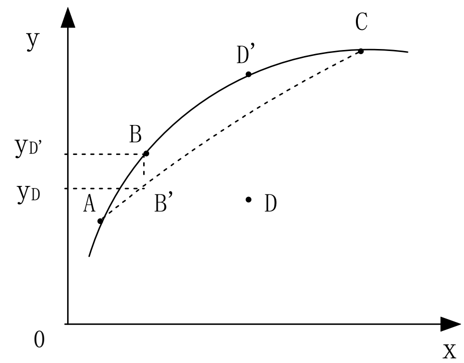

Fig. 2. Evaluation model of super-efficiency DEA

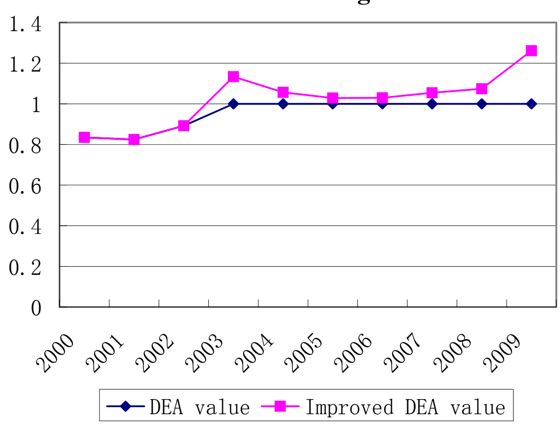

Fig. 3. The super-efficiency value of 10 DMUs

And then, Fig. 2 illustrates the theory of super-efficiency DEA. When calculate the efficiency value of B, we exclude it from the reference set, B' is the projection of B on the production frontier, thus the production frontier changed from ABC to AB'C, and the efficiency value of B became $y_B/y_{B'} > 1$. To D, which is ineffective in traditional model, the efficiency value still remains the same, that is less than 1. For the evaluation of decision making unit, we do not just need the result 'effective' or 'ineffective', but how to make the effective more efficient.

3 Practice and application

Now we apply the models into the efficiency evaluation of low carbon urbanization in Leshan center municipal district, one of the world natural and cultural inheritance area in western China.

3.1 Evaluation of low carbon urbanization

With the evaluation system built, we collect corresponding data from statistical yearbooks from 2000 to 2009 of Leshan center municipal district, and calculate them to be more improved and closer to the demand of indexes. And then, here comes to the calculation Tab. 3 and the data set which collected the 10 groups of data is supposed $U = \{$ 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009 $\}$, attribute set $R = \{X_1, X_2, X_3, \cdots, X_{27}\}$, and making a threshold limit for each property, 1 notes meeting the standards, that beyond the threshold limit, 2 motes that does not meet the standards, such as setting the threshold of 1.2 for x_1, then the data greater than 1.2 noted 1, otherwise noted 0.

Table 3. 2000 $\sim$ 2009 indicators of low carbon urbanization

Symbol	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
x_1	90.64	89.28	84.33	81.15	84.78	75.09	75.57	68.44	58.49	48.98
x_2	0.6	0.65	0.72	0.83	0.99	1.07	1.25	1.53	1.87	2.16
x_3	2306	2428	2572	2748	3154	3537	3829	4497	5192	5538
x_4	13.75	12.90	11.02	11.00	11.37	10.08	9.77	10.98	10.73	8.16
x_5	59.22	57.42	49.83	45.37	46.92	42.7	42.1	41.6	42	36.6
x_6	89.5	94.9	98	98.8	96.44	96.29	95.98	95.6	87.6	92.4
x_7	6.53	7.15	4.86	6.9	8.6	10	11.35	14.62	21.62	21.37
x_8	4.33	4.96	7.25	8.72	11.01	11.26	11.3	14.6	19.2	23.6
x_9	0	0	0.07	0.05	0	0.08	0.03	0.01	0	0
x_{10}	2.26	2.31	2.36	2.36	2.27	2.43	2.49	2.41	2.45	2.6
x_{11}	39.28	39.92	40.87	41.96	43.01	43.77	44.47	45.14	46.03	46.03
x_{12}	57.34	56.85	55.66	54.97	54.26	51.13	52.04	53.21	51.10	50.26
x_{13}	75.11	75.22	73.9	72.88	75.72	74.51	75.92	76.66	74.84	74.13
x_{14}	478.17	480.12	489.22	490.59	498.66	500.30	506.98	511.93	516.24	519.34
x_{15}	260.14	262.14	264.58	264.58	265.31	266.45	268.94	269.77	269.93	270.69
x_{16}	7	13	22	40	67	72	93	113	172	182
x_{17}	1.8	1.7	1.9	1.9	2.6	4.7	4.6	4.8	5.3	6.4
x_{18}	3.3	3.9	3.2	3.01	3.92	4.8	4.3	4.2	4	4.08
x_{19}	3.1	3.5	3.8	4.1	4.4	5.1	5.2	4.9	6.2	6.5
x_{20}	96.93	97.40	97.54	98.00	98.03	98.37	98.72	98.77	99.00	99.19
x_{21}	20.38	18.24	19.25	20.55	21.20	17.57	24.49	23.36	27.16	27.22
x_{22}	31.5	28.3	30.1	32.6	34.06	28.46	40.27	38.83	45.5	45.6
x_{23}	780.2	776.3	768.9	731.5	718	654.4	561.9	587.5	480.5	486.7
x_{24}	1.78	1.71	1.62	1.54	1.37	1.4	1.35	1.41	1.23	1.17
x_{25}	95.5	97.1	98.9	95.7	40.3	97.4	96	95.8	99.4	96.8
x_{26}	69	43	42	46.13	76.5	81.3	97.7	99	98.9	97.9
x_{27}	11.6	100	16.1	16.5	-9.2	16.6	15.3	16.9	62.1	9.4

Based on evaluation criteria of operational phase of new industrial indicators, and reference to the run target values of new industrialization of some industrialized cities in China in recent years, We set the threshold of 76.2 for x_1, 1.2 for x_2, 3580.1 for x_3, 11.1 for x_4, 45.9 for x_5, 97.6 for x_6, 11.3 for x_7, 11.02 for x_8, 0.028 for x_9, 2.33 for x_{10}, 43 for x_{11}, 53.85 for x_{12}, 74.15 for x_{13}, 499.155 for x_{14}, 266.253 for x_{15}, 70 for x_{16}, 4.5 for x_{17}, 3.8 for x_{18}, 5 for x_{19}, 98.195 for x_{20}, 21.94 for x_{21}, 35.4 for x_{22}, 654.9 for x_{23}, 1.4 for x_{24}, 91.3 for x_{25}, 77.1 for x_{26}, 15 for x_{27}. By the above rules we obtained Tab. 4. We can see that the corresponding property values of $x_2, x_3, x_7, x_{21}, x_{22}$ are the same, then only remain one property, we chose x_2. The corresponding property values of $x_{11}, x_{14}, x_{15}, x_{16}, x_{17}, x_{20}, x_{26}$, are the same, then only remain one property, we chose x_{17}.The corresponding property values of x_1, x_{12}, x_{23} are the same, then only remain one property, we chose x_1. Therefore we get Tab. 5.

Table 4. Evaluation Information

Symbol	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
x_1	1	1	1	1	1	0	0	0	0	0
x_2	0	0	0	0	0	0	1	1	1	1
x_3	0	0	0	0	0	0	1	1	1	1
x_4	1	1	0	0	1	0	0	0	0	0
x_5	1	1	1	0	1	0	0	0	0	0
x_6	0	0	0	0	0	0	0	0	0	0
x_7	0	0	0	0	0	0	1	1	1	1
x_8	0	0	0	0	0	1	1	1	1	1
x_9	0	0	1	1	0	1	1	0	0	0
x_{10}	0	0	1	1	0	1	1	1	1	1
x_{11}	0	0	0	0	0	1	1	1	1	1
x_{12}	1	1	1	1	1	0	0	0	0	0
x_{13}	1	1	0	0	1	1	1	1	1	0
x_{14}	0	0	0	0	0	1	1	1	1	1
x_{15}	0	0	0	0	0	1	1	1	1	1
x_{16}	0	0	0	0	0	1	1	1	1	1
x_{17}	0	0	0	0	0	1	1	1	1	1
x_{18}	0	1	0	0	1	1	1	1	1	1
x_{19}	0	0	0	0	0	1	1	0	1	1
x_{20}	0	0	0	0	0	1	1	1	1	1
x_{21}	0	0	0	0	0	0	1	1	1	1
x_{22}	0	0	0	0	0	0	1	1	1	1
x_{23}	1	1	1	1	1	0	0	0	0	0
x_{24}	1	1	1	1	0	0	0	0	0	0
x_{25}	1	1	1	1	0	1	1	1	1	1
x_{26}	0	0	0	0	0	1	1	1	1	1
x_{27}	0	0	1	1	0	1	1	1	1	1

The next step is to reduce the attributes in Tab. 5, that $U = \{2000, \cdots, 2009\}$ and property set $R = \{x_1, x_2, x_4, x_5, x_6, x_8, x_9, x_{10}, x_{13}, x_{17}, x_{18}, x_{19}, x_{24}, x_{25}, x_{27}\}$.

U/IND(R) = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008},{2009}},

U/IND$(R-\{x_1\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008},{2009}}= U/IND(R),

U/IND$(R-\{x_2\})$ = {{2000},{2001},{2002},{2003},{2004},{2005, 2006},{2007},{2008},{2009}}≠ U/IND(R),

U/IND$(R-\{x_4\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008},{2009}}= U/IND(R),

U/IND$(R-\{x_5\})$ = {{2000},{2001},{2002, 2003},{2004},{2005},{2006},{2007},{2008},{2009}}≠ U/IND(R),

U/IND$(R-\{x_6\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008},{2009}}= U/IND(R),

U/IND$(R-\{x_8\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008},{2009}} = U/IND(R),

U/IND$(R-\{x_9\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006, 2008},{2007},{2009}} ≠ U/IND(R),

U/IND$(R-\{x_{10}\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008},{2009}}= U/IND(R),

U/IND$(R-\{x_{13}\})$ = {{2000},{2001},{2002},{2003},{2004},{2005},{2006},{2007},{2008, 2009}}≠ U/IND(R),

U/IND$(R-\{x_{17}\})=\{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}=$ U/IND(R),
U/IND$(R-\{x_{18}\})=\{\{2000, 2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\neq$ U/IND(R),
U/IND$(R-\{x_{19}\})=\{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007, 2008\},\{2009\}\}\neq$ U/IND(R),
U/IND$(R-\{x_{24}\})=\{\{2000\},\{2001, 2004\},\{2002\},\{2003\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}\neq$ U/IND(R),
U/IND$(R-\{x_{25}\})=\{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}=$ U/IND(R),
U/IND$(R-\{x_{27}\})=\{\{2000\},\{2001\},\{2002\},\{2003\},\{2004\},\{2005\},\{2006\},\{2007\},\{2008\},\{2009\}\}=$ U/IND(R).

By the above steps, we know that $x_1, x_4, x_6, x_8, x_{10}, x_{17}, x_{25}, x_{27}$ can be omitted. Finally, we reduced the

Table 5. Preliminary reduction of evaluation information

Symbol	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
x_1	1	1	1	1	1	0	0	0	0	0
x_2	0	0	0	0	0	0	1	1	1	1
x_4	1	1	0	0	1	0	0	0	0	0
x_5	1	1	1	0	1	0	0	0	0	0
x_6	0	0	0	0	0	0	0	0	0	0
x_8	0	0	0	0	0	1	1	1	1	1
x_9	0	0	1	1	0	1	1	0	0	0
x_{10}	0	0	1	1	0	1	1	1	1	1
x_{13}	1	1	0	0	1	1	1	1	1	0
x_{17}	0	0	0	0	0	1	1	1	1	1
x_{18}	0	1	0	0	1	1	1	1	1	1
x_{19}	0	0	0	0	0	1	1	0	1	1
x_{24}	1	1	1	1	0	0	0	0	0	0
x_{25}	1	1	1	1	0	1	1	1	1	1
x_{27}	0	0	1	1	0	1	1	1	1	1

number of properties from 27 to 7, they are: GDP per capita, the share of primary industry in all employees, the share of R&D funds in GDP, ratio of urban Engel coefficient to rural Engel coefficient, urban registered unemployment rate, the share of college degree or above in total population, comprehensive energy consumption of 10 thousand GDP.

Then we evaluate the efficiency of new urbanization process. We get the input indexes from above: GDP per capita, the share of primary industry in all employees, the share of R&D funds in GDP, ratio of urban Engel coefficient to rural Engel coefficient, urban registered unemployment rate, the share of college degree or above in total population, comprehensive energy consumption of 10 thousand GDP, and we re-named them in order as $UI_1, UI_2, UI_3, UI_4, UI_5, UI_6, UI_7$, then according to the requirements of the development of low-carbon urbanization and the direction of future development in this area, we set the output indexes: GDP growth rate (%), residents' consumption expenses per capita ($Yuan$), comprehensive utilization rate of industrial and waste (%), that UO_1, UO_2, UO_3 [24, 25], evaluation system of SE-DEA in Tab. 6.

Therefore, to calculate the efficiency of DMUs, we have collected effective data in Tab. 6, and with the method of calculation like Eq. (6) and LINGO, a calculation software named interactive linear universal optimum computing solver, which really made our calculation simple and convenient, then in order to calculate the efficiency value of $Year_1$, that is 2000, we establish equation Eq. (7) by taking the values of the indicators in Tab. 6. Though solving equation Eq. (7), we get the efficiency value of 2000: 0.834425. Similarly, we solved the efficiency values of other DMUs in Tab. 7 and Fig. 3, listing the efficiency value and super efficiency value of each year and their rankings.

$$\min \quad \Theta \tag{7}$$

$$s.t\begin{cases} 0.65\lambda_2+0.72\lambda_3+0.83\lambda_4+0.99\lambda_5+1.07\lambda_6+1.25\lambda_7+1.53\lambda_8+1.87\lambda_9+2.16\lambda_{10}\leq 0.6\Theta \\ 57.42\lambda_2+49.83\lambda_3+45.37\lambda_4+46.92\lambda_5+42.7\lambda_6+42.1\lambda_7+41.6\lambda_8+42\lambda_9+36.6\lambda_{10}\leq 59.22\Theta \\ 0\lambda_2+0.07\lambda_3+0.05\lambda_4+0\lambda_5+0.08\lambda_6+0.03\lambda_7+0.01\lambda_8+0\lambda_9+0\lambda_{10}\leq 0\Theta \\ 75.22\lambda_2+73.9\lambda_3+72.88\lambda_4+75.72\lambda_5+74.51\lambda_6+75.92\lambda_7+76.66\lambda_8+74.84\lambda_9+74.13\lambda_{10}\leq 75.11\Theta \\ 3.9\lambda_2+3.2\lambda_3+3.01\lambda_4+3.92\lambda_5+4.8\lambda_6+4.3\lambda_7+4.2\lambda_8+4\lambda_9+4.08\lambda_{10}\leq 3.3\Theta \\ 3.5\lambda_2+3.8\lambda_3+4.1\lambda_4+4.4\lambda_5+5.1\lambda_6+5.2\lambda_7+4.9\lambda_8+6.2\lambda_9+6.5\lambda_{10}\leq 3.1\Theta \\ 1.71\lambda_2+1.62\lambda_3+1.54\lambda_4+1.37\lambda_5+1.4\lambda_6+1.35\lambda_7+1.41\lambda_8+1.23\lambda_9+1.17\lambda_{10}\leq 1.78\Theta \\ 9.2\lambda_2+12.3\lambda_3+14.3\lambda_4+15.1\lambda_5+13.5\lambda_6+15.1\lambda_7+15.4\lambda_8+14.1\lambda_9+15.5\lambda_{10}\geq 10 \\ 97\lambda_2+98.21\lambda_3+95.13\lambda_4+97.37\lambda_5+40.14\lambda_6+94.13\lambda_7+95.89\lambda_8+97.22\lambda_9+97.45\lambda_{10}\geq 95 \\ 3248.10\lambda_2+3471.79\lambda_3+3743.78\lambda_4+4328.52\lambda_5+4472.46\lambda_6+4739.50\lambda_7+5420\lambda_8 \\ +6130.50\lambda_9+6201.48\lambda_{10}\geq 3198.82 \\ \lambda j\geq 0,\ \ j=1,2,\cdots,10 \end{cases}$$

3.2 Analysis

From Tab. 7 and Fig. 3 we can make some conclusions about the trend or features of the 10 years' efficiency level of low carbon urbanization in this area and make some explanations.

Firstly, we can draw a conclusion that, in general, the level of low carbon urbanization is increasing gradually from 2000 $\sim$ 2009, though in different speed and even there are some drawbacks in special year. Secondly, in the first three years, that from 2000 $\sim$ 2002, the efficiency result are lower than 1, which is a relatively low class. Therefore, after detailed analysis, the main factors contributing to this problem are as follows. In the earlier years, economy in a weak foundation is the main factor that prevent urbanization. It is the industries in a weak basis and low relevancy that provides no more opportunities for a great deal of rural population to get a job or transfer their labor force to increase their income. Thirdly, from 2003 $\sim$ 2008, the efficiency is higher than 1 and keeps a gradually increased trend. In these years, economy develops, scale of industry expand, so it is with social service, and the level of low carbon urbanization promote. However, it increased slowly, and there are some reasons to explain. Single industry structure, extensive production and weak industry chain have shattered the regional economy space that it is hard to encourage the mobility of materials, products, capital and personnel among different villages and towns. Fourthly, in the year of 2009, it increases dramatically, government policy plays an important part in it. On the way of low carbon urbanization, city planning is an important aspect needs to be regarded. If an unreasonable city planning exists, there will be some traffic jams, environmental degradation, and each person can only share less resources. In this year, Leshan government has invested a lot not only on economy, but also on social service, environment protection and education career.

3.3 Suggestions

This paper here proposes several pieces of suggestions about advancing the low carbon urbanization in world natural and cultural heritage areas and the integration of urbanization and conservation on the way of it.
(1) Planning major construction reasonably and determining the major development fields. According to the idea of "modern function, high end industry", coordinating with optimizing function of the urban area, accelerate the construction of Sichuan Shopping Center, and make the East area agricultural, the West industrial, the South area touristique, the North logistical, and the Central section commercial as development orientation.
(2) Establishing rural community and building a new socialist countryside. In the process of realizing this goal, we should be adhere to the principle that firstly pilot projects and then gradual promotion. Firstly, as to the ideological work of rural residents, deal with the land use issues properly, ensure community construction land use, solve the problem of residential housing. Secondly, improve the government function of public services, list the special funds for community building, complete the community infrastructure construction well,

Table 6. Evaluation system of DEA

Symbol		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		1	2	3	4	5	6	7	8	9	10
Input	UI_1	0.6	0.65	0.72	0.83	0.99	1.07	1.25	1.53	1.87	2.16
	UI_2	59.22	57.42	49.83	45.37	46.92	42.7	42.1	41.6	42	36.6
	UI_3	0	0	0.07	0.05	0	0.08	0.03	0.01	0	0
	UI_4	75.11	75.22	73.9	72.88	75.72	74.51	75.92	76.66	74.84	74.13
	UI_5	3.3	3.9	3.2	3.01	3.92	4.8	4.3	4.2	4	4.08
	UI_6	3.1	3.5	3.8	4.1	4.4	5.1	5.2	4.9	6.2	6.5
	UI_7	1.78	1.71	1.62	1.54	1.37	1.4	1.35	1.41	1.23	1.17
Output	UO_1	10	9.2	12.3	14.3	15.1	13.5	15.1	15.4	14.1	15.5
	UO_2	95	97	98.21	95.13	97.37	40.14	94.13	95.89	97.22	97.45
	UO_3	3198.82	3248.10	3471.79	3743.78	4328.52	4472.46	4739.50	5420	6130.50	6201.48

Table 7. The super-efficiency values of 10 DMUs

Year	DEA value	Improved DEA value	Ranking
2000	0.834425	0.834425	9
2001	0.753901	0.753901	10
2002	0.891652	0.891652	8
2003	1	1.133682	2
2004	1	1.056514	4
2005	1	1.028321	7
2006	1	1.029375	6
2007	1	1.054044	5
2008	1	1.074021	3
2009	1	1.261481	1

establish service area for residents for their lives. Thirdly, form new community culture to enrich people's cultural life, strengthen exchanges between communities to improve life quality of population.

(3) Founding dynamic development mechanism of urbanization and enforcing the driving role of features. Firstly, strengthen the driving role of projects with depending on the driving force of government and the increasing domestic demand of each town to narrow the gap between small towns and the cities. Secondly, focus on improving the level of non-agricultural, economy development and general economic strength, increase security of social service level. Thirdly, make the preceding towns play leading role in the process of urbanization, conduct some disparity analysis to help the relatively weak towns and villages.

(4) Following the man-centered, intensive and sustainable low carbon road. Put great emphasize on principal position of population urbanization in rural-urban structure adjustment and promote the transformation of man-oriented low carbon urbanization pattern. Accelerate the localization of peasants, give consideration to the interests demand of different groups to benefit the whole public with urbanization development achievement. Improve the social security system, strengthen the public service providing capacity of city to support the disadvantaged groups.

(5) Pushing low carbon city construction. Firstly, put great emphasize on effective utilization of city space and build compact city. Put great emphasize on principal position of population urbanization in rural-urban structure adjustment and push forward the land marketization process, optimize land resources, adjust industrial structure, activate vitality of old city town. Perfect the city existing land use system, carry out the commercial land use rights competitive bidding system to form the mechanism that it is the market that determine the land price, which could make the price reflect the cost and allocation of the land. Secondly, we have to make use of the resources frugally and intensively and reduce the carbon emissions effectively, with the application and

extension of zero carbon and low carbon technology research in city development.
(6) Realizing the development, transformation and promotion in WNCH areas with the guidance of scientific development view. Control the land use, resident population and resident settlement, adjust the economy structure and transportation network, functional allocation, city development orientation and so on. And these measures are part of low carbon urbanization we define. And then, we should make the fully use of local features of WNCH areas by saving energy, recycle using of water resources and dispose of rubbish, encourage thrifty lifestyle and reduce material waste. The new demand and challenge of city planning is that we will make an ideal developing mode for sustainable development of WNCH areas.

4 Conclusion

This paper analyzes the level of low carbon urbanization in world natural and cultural heritage(WNCH) areas with rough set and improved DEA model. We can draw some conclusions from the experimental results and propose some constructional suggestions. Firstly, We project a concept named "low carbon urbanization" to solve urbanization and conservation in WNCH areas. Secondly, we build up a set of indexes to evaluate the efficiency of it. Thirdly, compromising of rough set and improved DEA model is a scientific way to assess low carbon urbanization, more accurate and efficient. The rankings are relatively accurate and rational, and give an exact positioning of this district and the suggestions we made before have certain reference value for evaluation of urbanization. Fourthly, the low carbon urbanization is a new concept we define, which, in some degree, provides a brand new development strategy in world natural and cultural heritage areas both in China and the world. And the most importantly, our duty is to arouse public awareness of low carbon urbanization and some measures to make a difference.

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